RHENIUM

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In the past decade, the two most important uses of rhenium have been in high-temperature superalloys and platinum-rhenium catalysts. High-temperature superalloys are used in turbine components in aircraft engines and other aerospace applications. Platinum-rhenium catalysts are used to produce high-octane, lead-free gasoline. Other applications of rhenium, primarily as tungsten-rhenium and molybdenum-rhenium alloys, are more diverse; these included electrical contact points, flashbulbs, heating elements, metallic coatings, temperature controls, thermocouples, vacuum tubes, and x-ray tubes and targets. Industry continued research on rhenium recovery from concentrates and the development of new alloys and catalysts.

In the United States, rhenium is a byproduct of molybdenite concentrates recovered as a byproduct of porphyry copper ore mined in the copper-molybdenum mines in the Western States. Domestic mine production data for rhenium were derived by the U.S. Geological Survey (USGS) from reported molybdenum production at the copper-molybdenum mines. Domestic demand for rhenium metal and other rhenium products was met principally by imports but also from domestic recovery and stocks. Metal powder and ammonium perrhenate (APR) values were estimated to be about $1,350 per kilogram and $1,000 per kilogram, respectively.

Consumption

U.S. apparent consumption of rhenium increased about 57% more than that of 2003 (table 1). A significant property of rhenium is its ability to alloy with molybdenum and tungsten. Molybdenum alloys containing about 50-weight-percent rhenium have greater ductility and can be fabricated by either warm or cold working. Unlike other molybdenum alloys, this type of alloy is ductile at temperatures above 196° C and can be welded. Alloys of tungsten with 24-weight-percent rhenium have improved ductility and have lower ductile-to-brittle transition temperatures than pure tungsten. Rhenium improves the strength properties of nickel alloys at high temperatures (1,000° C).

Metallurgical uses, such as in superalloys and powder metallurgy, were estimated to represent about 70% of rhenium consumption; an additional 20% was in reforming catalysts (Roskill Information Services Ltd., 2004, p. 46). Other uses for these alloys, which collectively represented only about 10% of total consumption, were in crucibles, electrical contacts, electromagnets, electron tubes and targets, heating elements, ionization gauges, mass spectrographs, metallic coatings, temperature controls, thermocouples, semiconductors, and vacuum tubes.

Rhenium is used in petroleum-reforming catalysts for the production of high-octane hydrocarbons, which are used in the formulation of lead-free gasoline. Bimetallic platinum-rhenium catalysts have replaced many of the monometallic catalysts. Rhenium catalysts tolerate greater amounts of carbon formation when making gasoline and make it possible to operate the production process at lower pressures and higher temperatures. This leads to improved yields (production per unit of catalyst used) and higher octane ratings. Platinum-rhenium catalysts also were used in the production of benzene, toluene, and xylenes, although this use was small compared with that used in gasoline production.

Foreign Trade

Imports of metal for consumption decreased by about 10%, while imports of APR sharply increased by about 500% owing to strong U.S. consumption (tables 2, 3). Imports for consumption of rhenium metal are listed in tables 1 and 2, and those of APR are listed in tables 1 and 3.

World Review

World production of rhenium was estimated to be about 37 metric tons (t) (table 4). That represents the quantity of rhenium recovered from concentrates that were processed to recover rhenium values. Rhenium was recovered as a byproduct from porphyry copper-molybdenum or porphyry copper concentrates mined in Armenia, Canada, Chile, Kazakhstan, Peru, Russia, the United States, and Uzbekistan. Rhenium metal and compounds were produced in Chile, China, Estonia, France, Germany, Kazakhstan, the Netherlands, the United Kingdom, and the United States.

World reserves of rhenium are contained primarily in molybdenite in porphyry copper deposits. U.S. reserves of rhenium are concentrated in Arizona, Montana, New Mexico, and Utah. Chilean reserves are found primarily at four large porphyry copper mines and in lesser deposits in the northern half of the country. In Peru, reserves are concentrated primarily in the Toquepala open pit porphyry copper mine and in about 12 other deposits. Other world reserves are in several porphyry copper deposits and sedimentary copper deposits in Armenia, northwestern China, Iran, Kazakhstan, Russia, and Uzbekistan and in sedimentary copper-cobalt deposits in Congo (Kinshasa). Identified U.S. resources are estimated to be about 4,500 t, and identified rest-of-the-world resources are estimated to be about 5,500 t.

Armenia.—Yerevan Pure Iron OJSC saw profits increase tenfold to $12 million in 2004 on rising global prices. Production volume grew by about 35% more than that of 2003 as the plant produced 1,900 t of ferromolybdenum, 250 t of metallic molybdenum, and 300 kilograms (kg) of rhenium. The Yerevan plant received molybdenum concentrates from shareholder CJSC Zangezur Copper & Molybdenum Plant. In 2005, investments in the Yerevan plant were expected to double molybdenum production capacity to about 7,000 t, including 5,000 t of ferromolybdenum. In 2004, the plant planned to produce 3,000 t of ferromolybdenum, 350 t of metallic molybdenum, and 500 kg of rhenium (Metal Pages, 2005§[1]). The plant's entire production was exported to Europe by Germany's Khronomet (owner of 51% the shares of the Yerevan plant and 60% of the shares of the Zangezur plant).

Chile.—Estimates of rhenium production were not readily available, as this information was considered proprietary, and the sales of recovered rhenium were mostly made under long-term contracts and were not published. It is generally assumed that about 50% of world rhenium production comes from Chile, and that the world consumption is about 40 to 45 metric tons per year (t/yr) (Taylor, 2002§). The leading producer of molybdenum concentrates in Chile is Corporación Nacional del Cobre (Codelco); most of their concentrates are roasted and processed for rhenium recovery by Molibdenos y Metales S.A. (Molymet). According to industry sources, Molymet also received concentrates from two other mines in Chile and at least one in Peru. Since 2000, Molymet received additional rhenium-bearing residues recovered from the stacks of the roasters at its subsidiary plant, Molymex S.A. de C.V. in Mexico. Molymex receives molybdenite concentrates from Grupo Mexico's La Caridad Mine and from producers in Canada, Chile, Peru, and the United States. The combined rhenium recovery by Molymet was estimated to be about 18.1 t in 2004.

Molymet announced plans to boost molybdenum concentrate processing capacity at the San Bernardo, Chile, plant by 18,000 t/yr (40 million pounds per year) and at its Sacaci subsidiary's plant in Ghent, Belgium, by 4,500 t/yr (10 million pounds per year). The expansion in Chile is expected to be completed in 2007, but the expansion in Belgium may not be completed until 2009. Molymet roasted molybdenum concentrates at plants in Belgium, Chile, and Mexico but only recovered rhenium at the Chile facility (Ryan's Notes, 2004).

Kazakhstan.—Kazakhstan's rhenium producer Zhezkazganredmet hoped for an increase in demand for rhenium from the Joint Strike Fighter Project, a North Atlantic Treaty Organization project. The project is slated to deliver about 3,000 aircraft, requiring more than 6,000 engines, starting in 2008, and it will begin requiring rhenium for engine manufacture in 2005-06. Rhenium demand suffered after the September 11, 2001, terrorist attacks on the United States that caused Western economies and the airline industry to struggle and caused a reduction in jet engine orders. Demand for rhenium in the United States, the world's leading consumer, dropped by about 40% after 2001 but has since recovered (Metal Pages, 2003a§). Zhezkazganredmet operated below capacity in 2002 and 2003 owing to the weak rhenium market and reorganization of the company. Zhezkazganredmet's current APR production capacity is believed to be about 1,000 kilograms per month.

Russia.—Kyshtym Copper-Electrolyte Works (KMEZ) in the Chelyabinsk region of Russia, a major copper producer, produced a trial batch of rhenium in July 2003 (Metal Pages, 2003b§). A pilot plant was deployed in the crater at the Kudryavyl Volcano on Iturup Island by researchers of the Volcanology and Geodynamics Institute, Russian Academy of Sciences to extract rhenium from the volcanic gas (Metal Pages, 2003c§). No further developments on these Russian efforts to develop capacity to recover rhenium were reported in 2004.

Current Research and Technology

A new, fourth-generation, single-crystal superalloy has been jointly developed by General Electric Aircraft Engines, Pratt & Whitney, and the National Aeronautics and Space Administration. The focus of the effort was to develop a turbine airfoil alloy with long-term durability for use in the high-speed civil transport, a supersonic passenger jet plane. In order to achieve adequate longtime strength improvements at moderate temperatures and retain good microstructure stability, it was necessary to make significant composition changes from second- and third-generation single-crystal superalloys. These included lower chromium levels, higher cobalt and rhenium levels, and the inclusion of a new alloying element, ruthenium. It was found that higher cobalt levels were beneficial to reducing both topologically close-packed phase formations and secondary reaction-zone formation. Ruthenium was determined to be a critical element to the success of the alloy development program because it could be added to achieve both improved microstructure stability and increased high-temperature creep strength. Ruthenium caused the refractory elements to partition more strongly to the γ' phase, which resulted in better overall alloy stability. The final alloy, EPM-102, had significant creep rupture and fatigue improvements over the baseline production alloys and had acceptable microstructure stability. The alloy is currently being engine tested and evaluated for advanced engine applications (Walston and others, 2004§).

Outlook

The rhenium market was boosted at the Paris Air Show when the United Arab Emirates ordered 20 Airbus A340s (Metal Pages, 2003d§). The Airbus A340 features four rhenium-containing Rolls Royce Trent 500 engines with two single-crystal blade sections, one with 3% rhenium and another with 6% rhenium. The Boeing 777 features two Trent 800 engines, the Airbus A380 features four Trent 900 engines, and the Boeing 787 features two Trent 1000 engines, all of them with rhenium-containing, single-crystal blade sections. These applications take advantage of improved creep resistance of the higher-rhenium-content alloy.

Current world demand for rhenium is not expected to decrease during the coming years and will likely only increase. Demand for rhenium in nickel-base superalloys accounts for about 60% of world rhenium consumption. The Joint Strike Force Fighter Project is expected to involve about 3,000 aircraft and 6,000 engines using high-rhenium content superalloys (Journal of Metals, 2004). Finally,

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[1]References that include a section mark (§) are found in the Internet References Cited section.

trade sources reported good demand from the catalyst sector, with plans announced for development of a new rhenium-containing catalyst.

Perhaps the greatest potential for increased rhenium production lies in the molybdenum concentrates that are presently being roasted in facilities that are not equipped to recover the rhenium values. For instance, a significant portion of the molybdenum concentrate production of Codelco, the leading producer of molybdenum concentrates in Chile, is exported unroasted or roasted without rhenium recovery. It has been estimated that capturing lost rhenium could increase world rhenium production capacity by about 12 t/yr (Roskill Information Services Ltd., 2004, p. 84).

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TABLE 1
SALIENT U.S. RHENIUM STATISTICS[1]

(Kilograms of gross weight)

	2000	2001	2002	2003	2004
Supply[2]	7,200 r	5,500	4,000	3,900	5,900
Apparent consumption[e, 3]	25,400	30,300	22,100	19,000	29,800
Imports:					
Metal	12,400 r	20,200	14,300	13,200	11,800
Ammonium perrhenate	5,750 r	4,560	3,780 r	1,990	12,100

[e]Estimated. [r]Revised.

[1]Data are rounded to no more than three significant digits.

[2]Rhenium contained in molybdenite concentrates, based on calculations by the U.S. Geological Survey.

[3]Calculated as production plus imports minus exports and industry stock changes.

TABLE 2

U.S. IMPORTS FOR CONSUMPTION OF RHENIUM METAL, BY COUNTRY[1]

	2003		2004	
Country	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Austria	--	--	2	$3
Belgium	--	--	8	9
Chile	12,700	$14,000	10,700	11,700
China	3	3	--	--
France	21	31	4	4
Germany	396	322	1,060	1,130
Japan	2	2	--	--
Netherlands	33	40	14	14
Russia	--	--	5	7
United Kingdom	--	--	4	9
Total	13,200	14,400	11,800	12,900

-- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau, with adjustments by the U.S. Geological Survey.

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF AMMONIUM PERRHENATE, BY COUNTRY[1]

	2003		2004	
Country	Gross weight (kilograms)	Value (thousands)	Gross weight (kilograms)	Value (thousands)
Belgium	371	$298	--	--
China	--	--	666	$618
Estonia	183	105	1,500	17
France	--	--	253	321
Germany	959	821	1,660	672
Kazakhstan	329	216	4,950	4,020
Korea, Republic of	--	--	--	--
Netherlands	144	122	2,630	1,690
United Kingdom	--	--	400	226
Total	1,990	1,560	12,100	7,560

-- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau, with adjustments by the U.S. Geological Survey.

TABLE 4

RHENIUM: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Kilograms)

Country	2000	2001	2002	2003	2004
Armenia	700	750	800	1,000	1,000
Canada	1,600	1,700	1,700	1,700	1,700
Chile[e, 3]	15,200 r	15,900 r	15,100 r	15,800 r	18,100
Kazakhstan	2,400	2,500	2,600	2,600	2,600
Peru	4,800	5,000	5,000	5,000	5,000
Russia	1,100	1,200	1,400	1,400	1,400
United States[4]	7,200 r	5,500	4,000	3,900	5,900
Uzbekistan	NA	NA	NA	NA	NA
Other	3,000	590	1,000	1,000	1,000
Total	36,000 r	33,100 r	31,600 r	32,400	36,700

[r]Revised. NA Not available.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Table includes data available through June 13, 2005.

[3]Data revised based on new information from Comisión Chilena del Cobre; also includes rhenium content from Mexico processed at Molyibdenos y Metales S.A. in Chile.

[4]Calculated rhenium contained in molybdenite concentrates.